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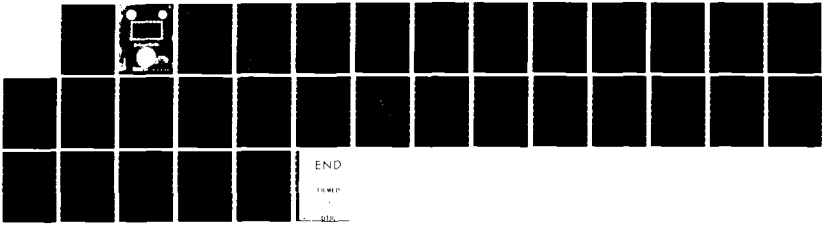

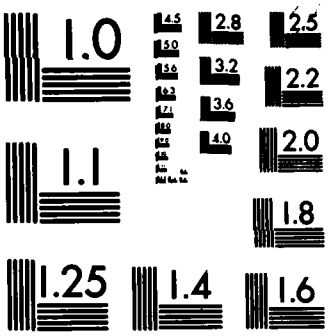

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DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407

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MANNED EVALUATION OF MK-15 CLOSED-CIRCUIT UBA CANNISTER DURATION AT 13.4°C AND 2°C

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June 1983

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CO_2 Absorbent	Oxygen Consumption
Exercise	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The CO_2 absorbent cannister duration of the MK-15 closed-circuit Underwater Breathing Apparatus (UBA) was evaluated during moderate exercise in cold water of 13.4°C and 2°C at 65 FSW. The Passive Diver Thermal Protection System (PDTPS) was worn during the study to evaluate the thermal protection it provides at 65 FSW. Results demonstrate that the safe operational limit of the MK-15 UBA is 117.5 minutes at either 13.4°C or 2°C and the PDTPS provides adequate thermal protection to the diver operating in these temperatures at 65 FSW.

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ABSTRACT

The CO_2 absorbent cannister duration of the MK-15 closed-circuit Underwater Breathing Apparatus (UBA) was evaluated during moderate exercise in cold water of 13.4°C and 2°C at 65 FSW. The Passive Diver Thermal Protection System (PDTPS) was worn during the study to evaluate the thermal protection it provides at 65 FSW. Results demonstrate that the safe operational limit of the MK-15 UBA is 117.5 minutes at either 13.4°C or 2°C and the PDTPS provides adequate thermal protection to the diver operating in these temperatures at 65 FSW.

KEY WORDS

MK-15

Closed-Circuit UBA

Cannister Duration

CO_2 Absorbent

Exercise

PDTPS

Thermal Protection

Cold Water

Oxygen Consumption

INTRODUCTION

The MK 15 Underwater Breathing Apparatus (UBA) is a closed circuit UBA used by the Naval Special Warfare Community for clandestine combat swimmer operations. It monitors and automatically maintains inspired PO_2 at a pre-set level of 0.7 $\pm$ 0.10 ATA by adding oxygen to the breathing loop as it is metabolically consumed. The breathing gases are completely contained within the UBA breathing loop with no losses to the surrounding water except on ascent. The diver's exhaled gas passes through a CO_2 absorbent cannister which extracts the metabolically produced CO_2 from the exhaled gas. The designed submerged operation time of the MK 15 based on oxygen bottle capacity is six hours. The safe operational limit is further reduced by cannister duration. For a more detailed description of the MK 15 UBA see references 1 and 2.

This report describes the results of a CO_2 cannister duration study performed during an air saturation dive series at the Navy Experimental Diving Unit (NEDU) in the Ocean Simulation Facility (OSF) Hyperbaric Chamber Complex using the MK-15 UBA. Cannister duration tests were conducted at 65 FSW in 13.4°C and 2°C water to evaluate the effects of these temperatures on the CO_2 cannister duration and to establish a safe operational limit for the MK-15 at this temperature and depth. The breathing medium for all studies was N_2-O_2.

METHODS

All of the dive subjects were U.S. Navy divers familiar with the operation of the MK 15 UBA. Their physical characteristics are given in Table 1.

TABLE 1

	DIVER CHARACTERISTICS		
Diver #	Age (yrs)	Height (inches)	Weight (lbs)
1	24	71.0	175
2	35	71.5	160
3	22	75.25	185.5
4	36	68.0	176
5	32	66.0	150.5
6	33	76.0	189.0

All dives were conducted in the OSF wet chamber chilled to either 13.4°C (56.1°F) or 2°C (35.6°F). The chamber was pressurized to 60 FSW with a platform in the Wet Chamber 5 feet below the water level, resulting in a total depth of the diver of 65 FSW. Exercise was provided by two pedal-mode ergometers (3) which were placed on the platform in a 45 degree head-up attitude. This allowed two MK-15 Diver-Subjects to exercise simultaneously, thereby doubling the number of runs which could be accomplished each day. A standby diver with communications to the surface was ready to assist the divers during all tests. The MK-15 diver had no communications other than hand signals.

Each diver wore the Passive Diver Thermal Protection System (PDTPS) which consisted of full long john underwear, wool socks, Thinsulate thermal undergarment with hood, dry suit outer garment with gloves, and weights at the midline, rectal probe and thermal belt (4). This enabled the collection of objective data on the thermal protection afforded by the PDTPS at 65 FSW. Thermal stress was defined as a rectal temperature drop of 2°C.

The initial UBA set up and all canister changes were done on the surface. Prior to each dive day, three MK-15 UBA's were set to maintain PO_2 at 0.70 $\pm$ 0.05 ATA. To prevent dive termination due to an exhausted diluent gas supply, each UBA was provided with an umbilical air supply for diluent gas in place of the diluent bottle. A fresh battery was used for each dive and the cannisters were freshly packed and weighed using the same batch of High Performance (H.P.) SODASORB throughout all cannister duration studies.

Cannister effluent CO_2 and O_2 gas samples were obtained by small diameter (.032 in. i.d.) capillary sample lines with sampling rates of 300 to 700

cc/min (STPD). A micrometering valve at the sample origin for flow control allowed a delay time of less than two seconds and provided rapid response to variations in gas composition without significant mixing in the sample line. The gas samples were analyzed by either a Perkin Elmer MGA 1100 or a Chemetron Model 7401 mass spectrometer. An accuracy of $\pm$ 0.01% was obtained by frequent calibrations during the experiment.

The oxygen bottle pressure was measured by a Validyne DP 15 Pressure Transducer equipped with a 3000 psig $\pm$ 1% diaphragm. This transducer was calibrated from 0-2500 psi against a Mensor 11600 digital pressure gauge (2500 psi $\pm$ 0.04%) before and after each study. A linear regression of Validyne voltage versus digital pressure gauge reading was calculated by a HP-1000 computer. The Validyne output voltage was then directly converted to pounds per square inch each time the computer sampled. After each run, a plot of oxygen bottle pressure versus time was made and the oxygen consumption was estimated from this plot as will be described.

A Hewlett Packard HP-1000 computer sampled and recorded the cannister effluent PCO_2, PO_2 and oxygen bottle pressure at 10 second intervals. A Gould strip chart recorder recorded these results and they were stored by the computer for future retrieval.

Once all the equipment was checked and calibrated, the divers entered the water and mounted the ergometers. Rectal temperatures were continuously recorded by the HP-1000 computer via a YSI 702A temperature probe. After an initial rest period of 5 minutes, the divers began an alternating sequence of 6 minutes of work at 50 watts followed by 4 minutes of rest. The dives were terminated when the cannister effluent CO_2 exceeded 1.0% Surface Equivalent

Value (SEV) (7.6 mmHg) or the total time on the MK-15 UBA exceeded 4 hours. Criteria for changing divers on the same UBA were rectal temperature drop of 2°C, fatigue or coldness of the diver, or rig failure without CO_2 limits having been exceeded.

RESULTS

A total of 12 cannister duration dives were completed in connection with the MK-15 UBA evaluation. Seven of these dives were conducted at 13.4°C and five at 2°C. The cannister effluent CO_2 versus time plots for each diver are found in the Annex, Figures 1A-12A. The cannister effluent CO_2 tension rises as exercise begins and then falls during the intervening rest periods, thus forming a jagged sinusoidal pattern. The cannister duration times were computed by drawing a smooth curve through the mean peak CO_2 values for the final minute of exercise on the cannister effluent CO_2 versus time graph. The point of intersection of this curve with CO_2 effluent axis representing 0.5% SEV and 1.0% SEV was determined and tabulated. Table 2 summarizes the $\dot{V}O_2$, pre and post dive cannister weights, and the time to reach a CO_2 effluent of 0.5% SEV and 1.0% SEV for each dive.

Cannister breakthrough time was defined as the mean of the individual times for the PCO_2 to reach 0.5% SEV (3.8 mmHg). The cannister breakthrough time was calculated to be 169.3 $\pm$ 60.6 minutes at 13.4°C and 165.4 $\pm$ 38.5 minutes at 2°C.

During the 12 dive study, three dives, two at 13.4°C and one at 2°C, did not reach 1.0% SEV in four hours. The time to reach either 0.5% SEV or 1.0% SEV for these were estimated by extrapolation as shown in Table 2. In one dive, cannister breakthrough was extremely short reaching 0.5% SEV in 75

TABLE 2

MK 15 CANISTER DURATION AT 65 FSW

13.4°C

Diver #	Canister Weight(kg) Pre-dive	Canister Weight(kg) Post-dive	$\dot{V}O_2$ (l/min)	Minutes to 0.5% SEV	Minutes to 1.0% SEV
1/2	4.252	4.745	1.65	150.0	208.1
3	4.130	4.860	1.81	176.2	217.5
4	4.230	4.762	1.95	120.0	181.9
5	4.166	4.708	1.57	219.4	251.2*
2/1	4.150	4.773	1.40	189.4	243.8
6	4.220	4.521	1.58	75.0	—
6	4.180	4.672	1.50	255.0*	—
Mean	4.190±.045	4.720±0.10	1.64±0.19	169.3±60.6	220.5±28.0

2°C

Diver #	Canister Weight(kg) Pre-dive	Canister Weight(kg) Post-dive	$\dot{V}O_2$ (l/min)	Minutes to 0.5% SEV	Minutes to 1.0% SEV
2	4.152	4.770	1.56	183.8	217.5
3	4.176	4.782	1.66	206.2	258.8*
4	4.198	4.743	2.11	103.1	151.8
5	4.192	4.635	1.46	170.6	235.0*
6	4.193	4.801	1.85	163.1	217.5
Mean	4.182±0.02	4.746±0.06	1.73±0.26	165.4±38.5	216.1±39.8

* Data did not extend to this point. Values estimated via extrapolation.

minutes. This dive was terminated and the CO_2 cannister was replaced. The same diver reentered the water with the same UBA under the same conditions but with a new CO_2 cannister. This second run did not reach 0.5% SEV CO_2 effluent until after four hours had elapsed. Examination of the first CO_2 absorbent cannister revealed no obvious cause for malfunction.

On two dives the divers were replaced during a rest cycle and the dive continued. Both changes occurred at 13.4°C and are designated as Diver #1/2 and 2/1 in Table 2. One was replaced because the diver complained of feeling cold and the other because of leg cramps. Even though some divers felt cold, no diver rectal temperature fell more than 2°C during any run. This indicates that the PDTPS provides adequate thermal protection for the swimming diver at temperatures to 2°C at 65 FSW.

An example of the oxygen bottle pressure versus time is shown in Figure 1. The steep decrease in bottle pressure with exercise is followed by a slight increase (as the bottle warms) during rest as shown in the figure. A straight line was fitted to this plot by hand, the slope of which represents the mean rate of oxygen bottle pressure drop for the entire run. Oxygen consumption can be calculated from the formula (if there were no leaks from the UBA):

$$\dot{V}_{O_2} = (\Delta P/\Delta T) \cdot (V_B/14.7) \cdot [273/(T+273)] - V_S \cdot F_{O_{2S}}$$

where:

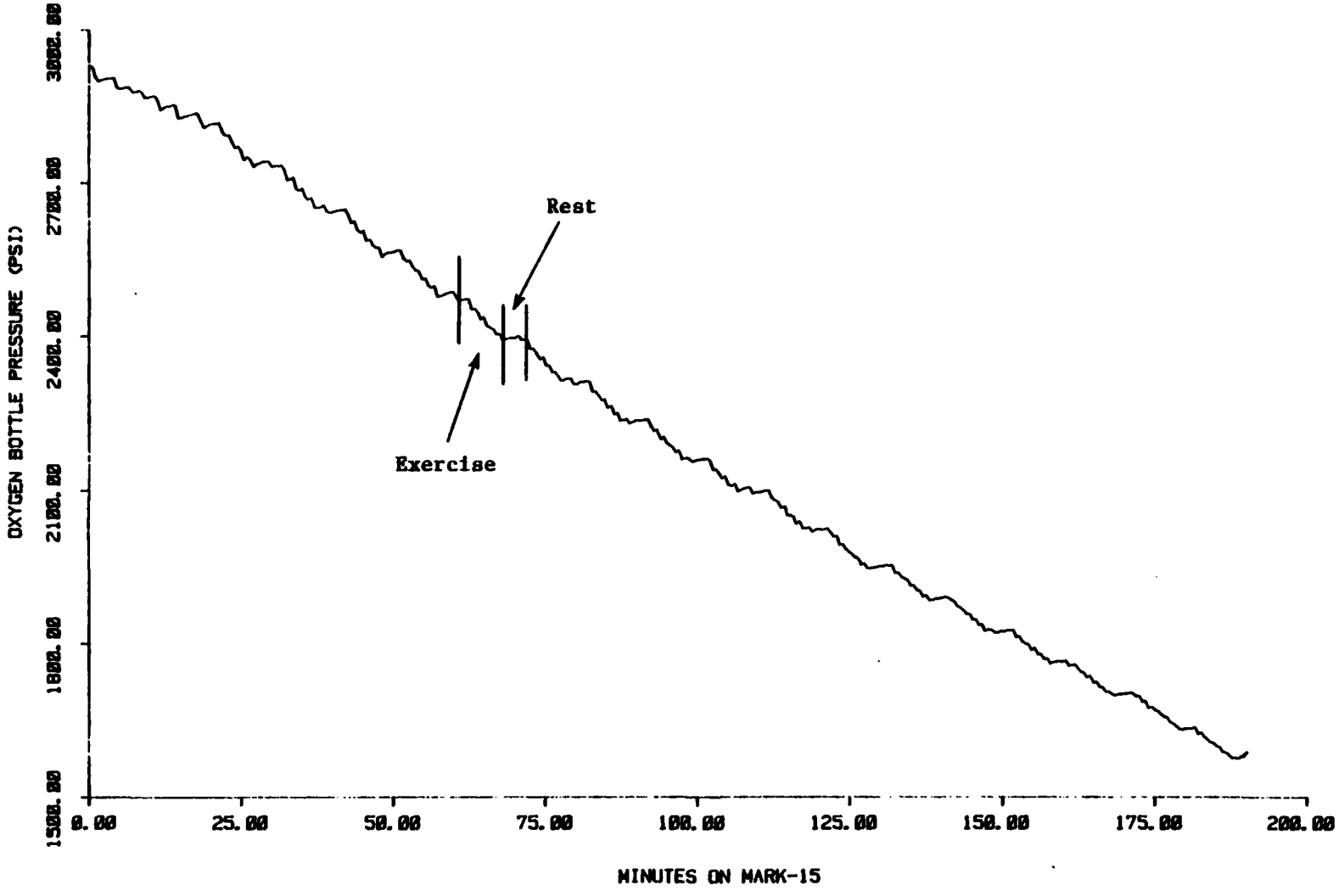

FIGURE 1. OXYGEN BOTTLE PRESSURE 2°C/65FSW DIVER #5 18 JANUARY 1983

$\dot{V}_{O_2}$ = O_2 consumption (l/min STPD)

$\Delta P/\Delta T$ = Slope of O_2 pressure plot (psi/min)

V_B = O_2 bottle volume (l)

14.7 = PSI/ATA conversion factor

T = O_2 bottle temperature (°C)

V_S = UBA gas sample rate (SLPM)

$F_{O_{2_S}}$ = Oxygen fraction in gas sample

DISCUSSION

Cannister duration times exhibited wide individual variability (Table 2). Cannister duration is probably affected by several factors, mainly ambient temperature, flow rate of gas through cannister, and breathing patterns. Unpublished observations during unmanned testing at NEDU show that small changes in CO_2 production rates may make large changes in cannister duration. Additional variables were controlled in this study by packing and weighing all canisters within 1% of each other using the same batch of H.P. SODASORB for the entire study (Table 2). Therefore, the observed differences in canister duration must be attributed to individual breathing patterns and CO_2 production.

One diver reached cannister breakthrough in a very short time of 75 minutes (Figure 6A). The cannister was replaced and the same diver reentered the water. The second cannister did not reach breakthrough in the four hour limit. Both cannisters were packed and weighed by the same individual using

the same batch of H.P. SODASORB and were within 1% weight of each other. The same diver using the same UBA under the same conditions, nevertheless, produced vastly different breakthrough times. The reason for this variability is not known, but previous studies have also shown a wide variation of cannister durations without a reasonable explanation (5).

The designation of 0.5% SEV used to establish cannister breakthrough time is not a physiological limit but a practical one based on the shape of the CO_2 effluent curve and the need for a standardized endpoint. Inspired CO_2 levels up to 2% SEV are safe to breathe but levels above this cause increasing detrimental physiological effects (6). As seen in the Annex, Figures 1A-12A, once the 0.5% SEV level is reached, the CO_2 level reaches 1% SEV in a few more work cycles and would probably exceed 2% SEV shortly thereafter.

The mean times to reach cannister effluent CO_2 of 0.5% SEV in these studies were 169.3 $\pm$ 60.6 minutes and 165.4 $\pm$ 38.5 minutes at 13.4°C and 2°C respectively. These two values are within the statistical limits to conclude that there is no statistical difference between the cannister durations at these two temperatures. The mean of all 12 times to 0.5% SEV for either temperature is 167.6 $\pm$ 50.4 minutes.

In addition, the short cannister breakthrough of 75 minutes, as discussed above, though vastly different is unexplainable and must be considered a feasible occurrence during normal operations and thus statistically significant. It, therefore, should not be excluded in the statistical derivation of the safe operational cannister duration. However, if the mean cannister duration time is computed without using the 75 minute duration, the mean duration time would be 176.1 $\pm$ 43.1. Thus, the mean duration is shortened 9 minutes by including the 75 minute time.

The operational limit is derived by subtracting one standard deviation from the mean time to reach cannister breakthrough (0.5% SEV). In this study, therefore, it has been determined that for dive planning purposes the safe operational CO_2 absorbent cannister limit is 117.5 minutes for temperatures between 13.4°C and 2°C at 65 FSW. In view of shorter duration always being possible, the divers must be reminded that symptoms of CO_2 build up must not be ignored at any time they occur during a dive.

CONCLUSIONS

1. There is no difference in cannister duration time for the MK-15 UBA breathing N_2O_2 between 13.4°C and 2°C water temperature.

2. The operational limit for the MK-15 UBA over a water temperature range of 2°C to 13.4°C is 117.5 minutes when using an N_2O_2 breathing medium.

3. The PDTPS provided adequate thermal protection from 152 to 260 minutes in 2°C water.

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ANNEX

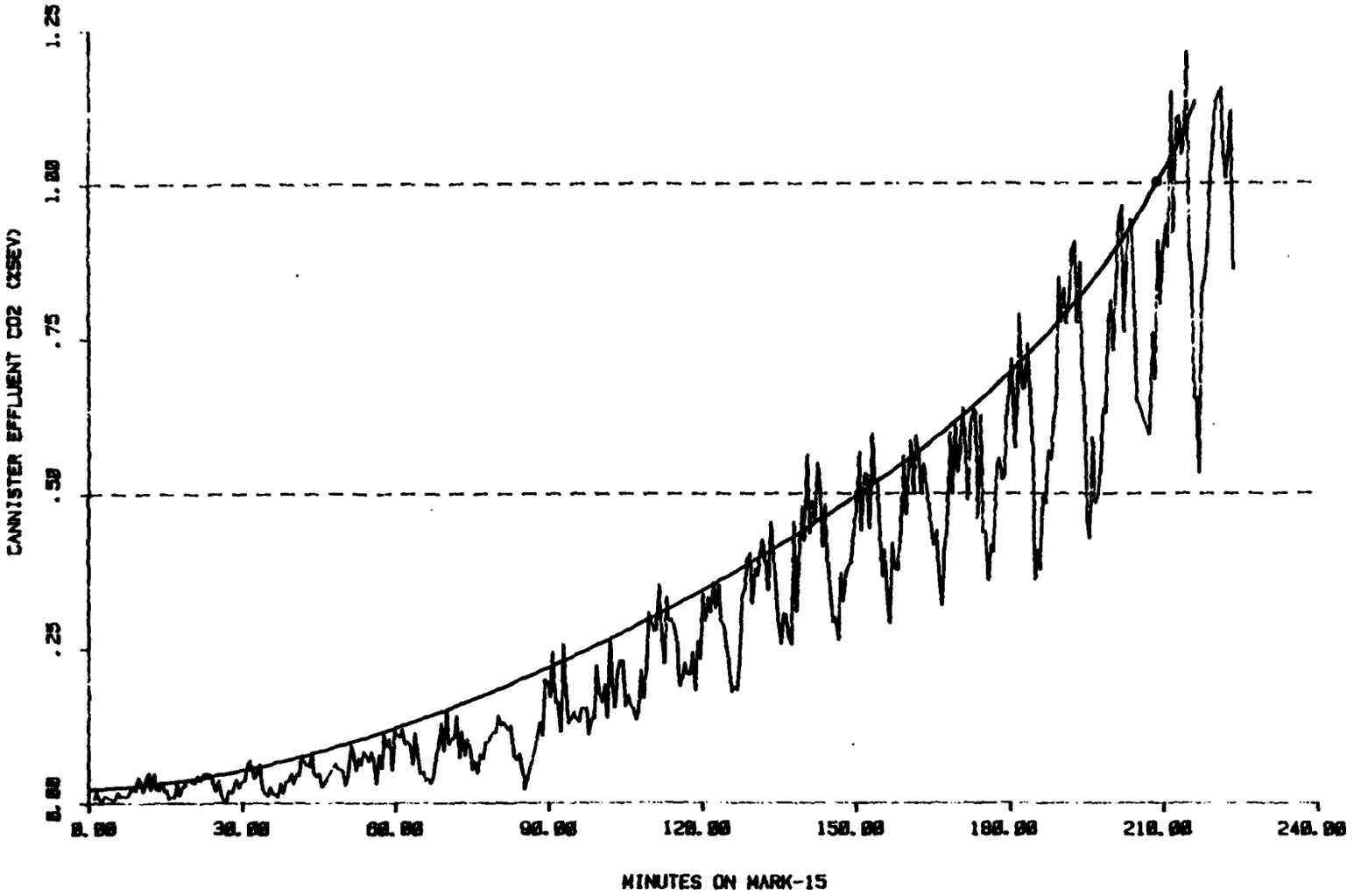

FIGURE 1A. MARK-15 CANNISTER DURATION 13.4°C/65FSW DIVER #1/2 19 JANUARY 1983 MEAN VO_2 = 1.65 L/MIN (STPD)

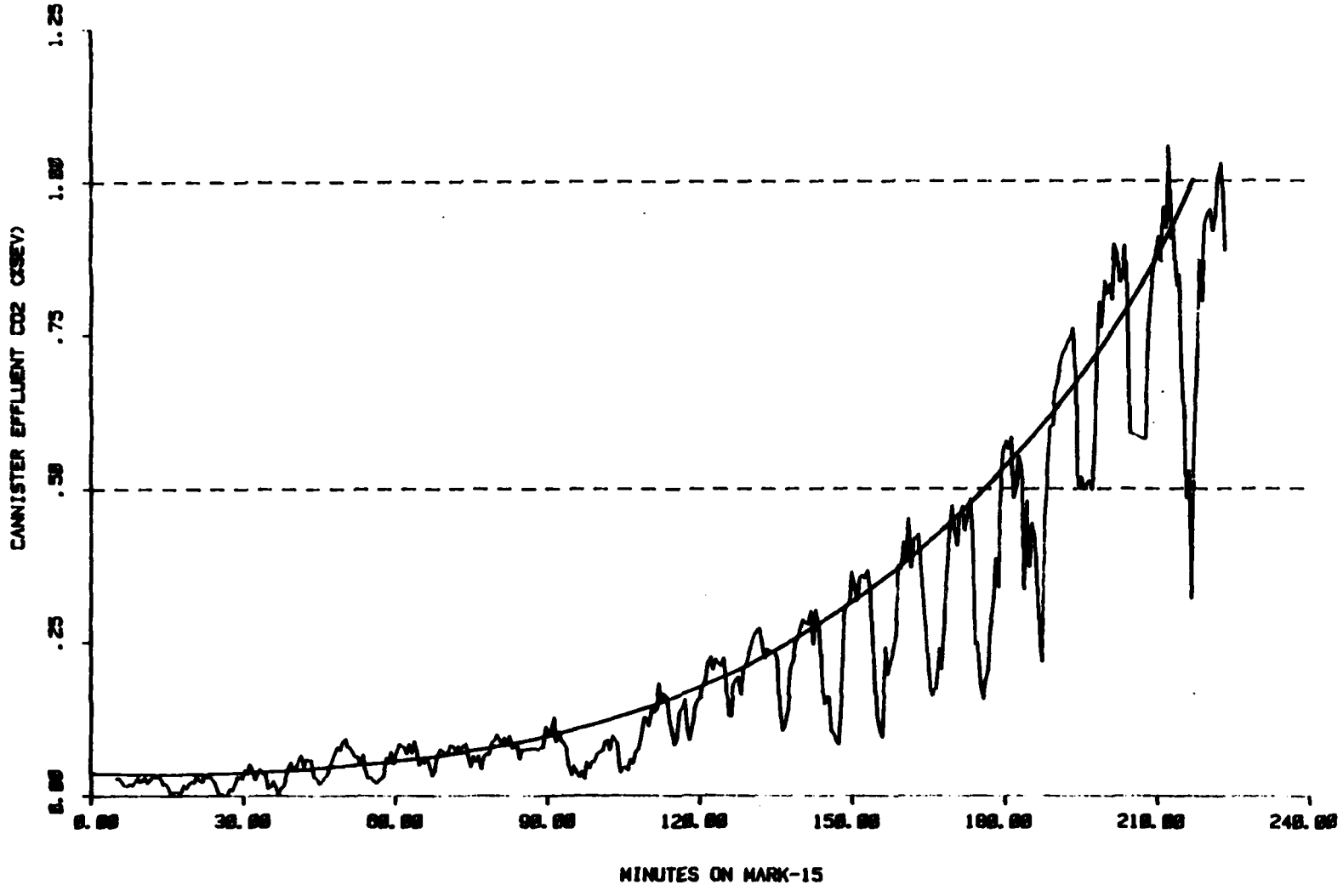

FIGURE 2A. MARK-15 CANNISTER DURATION 13.4°C/65FSW DIVER #3 19 JANUARY 1983 MEAN VO_2 = 1.81 L/MIN (STPD)

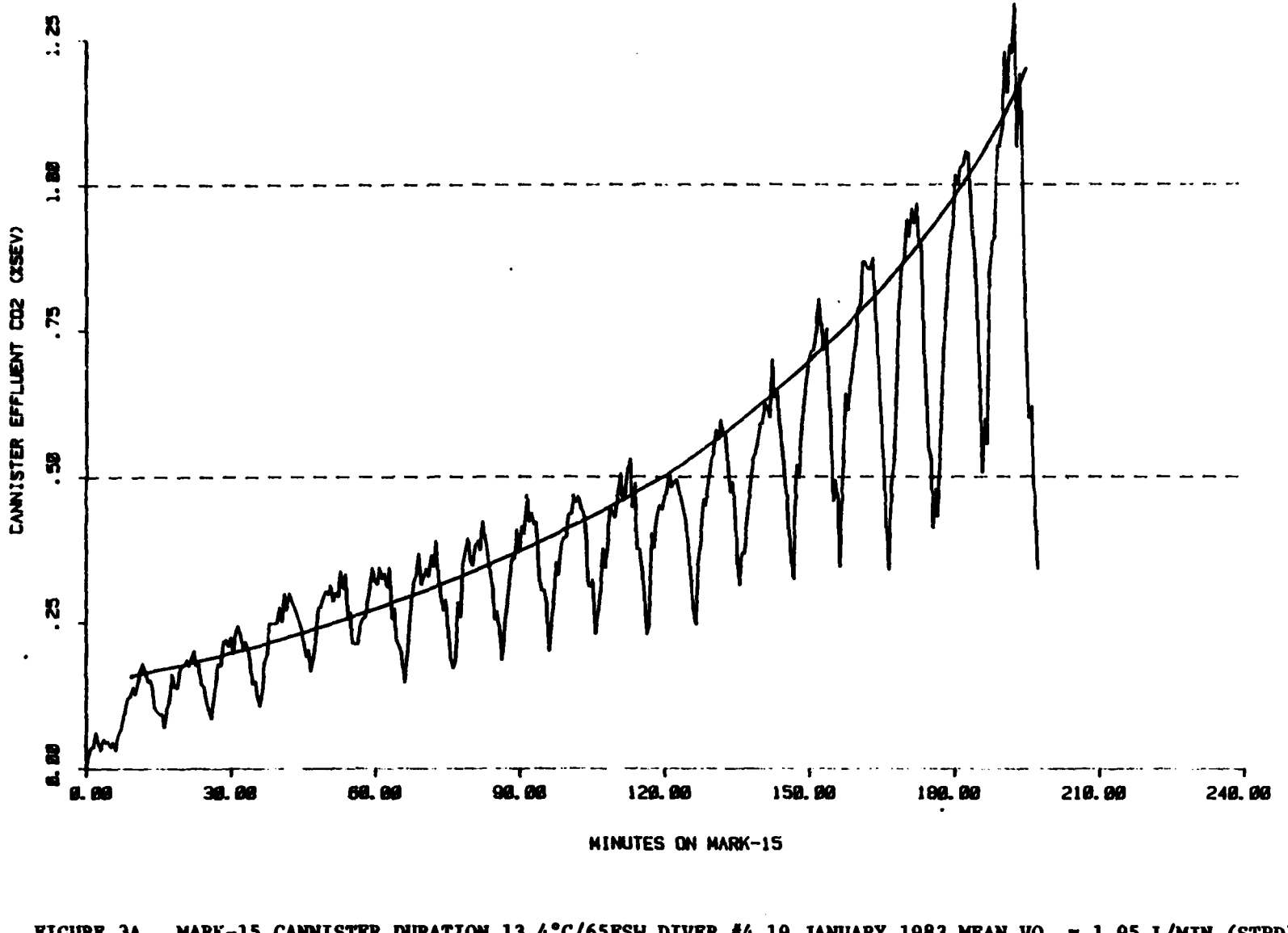

FIGURE 3A. MARK-15 CANNISTER DURATION 13.4°C/65FSW DIVER #4 19 JANUARY 1983 MEAN VO_2 = 1.95 L/MIN (STPD)

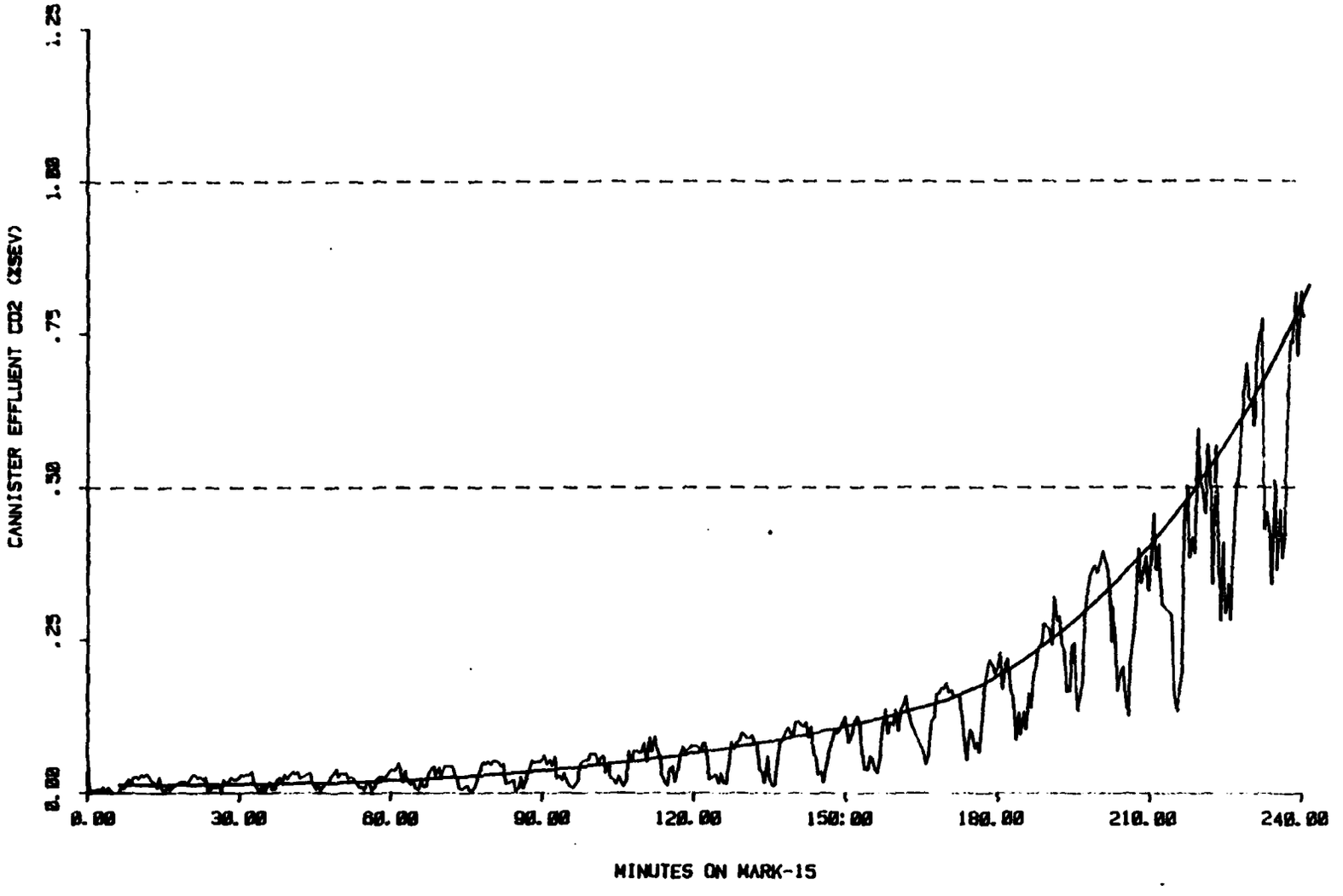

FIGURE 4A. MARK-15 CANNISTER DURATION 13.4°C/65FSW DIVER #5 19 JANUARY 1983 MEAN VO_2 = 1.57 L/MIN (STPD)

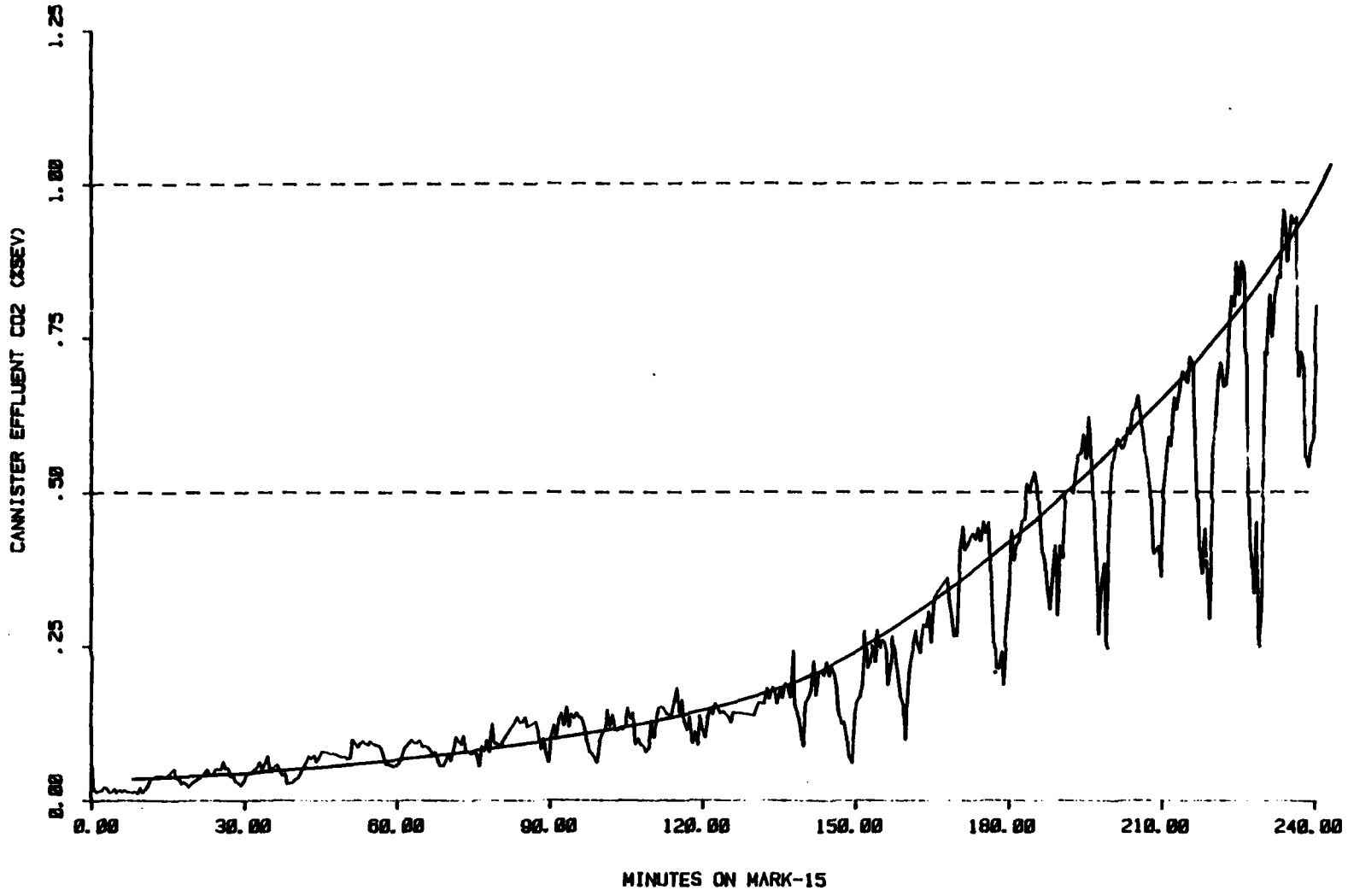

FIGURE 5A. MARK-15 CANNISTER DURATION 13.4°C/65FSW DIVER #2/1 20 JANUARY 1983 MEAN VO_2 = 1.40 L/MIN (STPD)

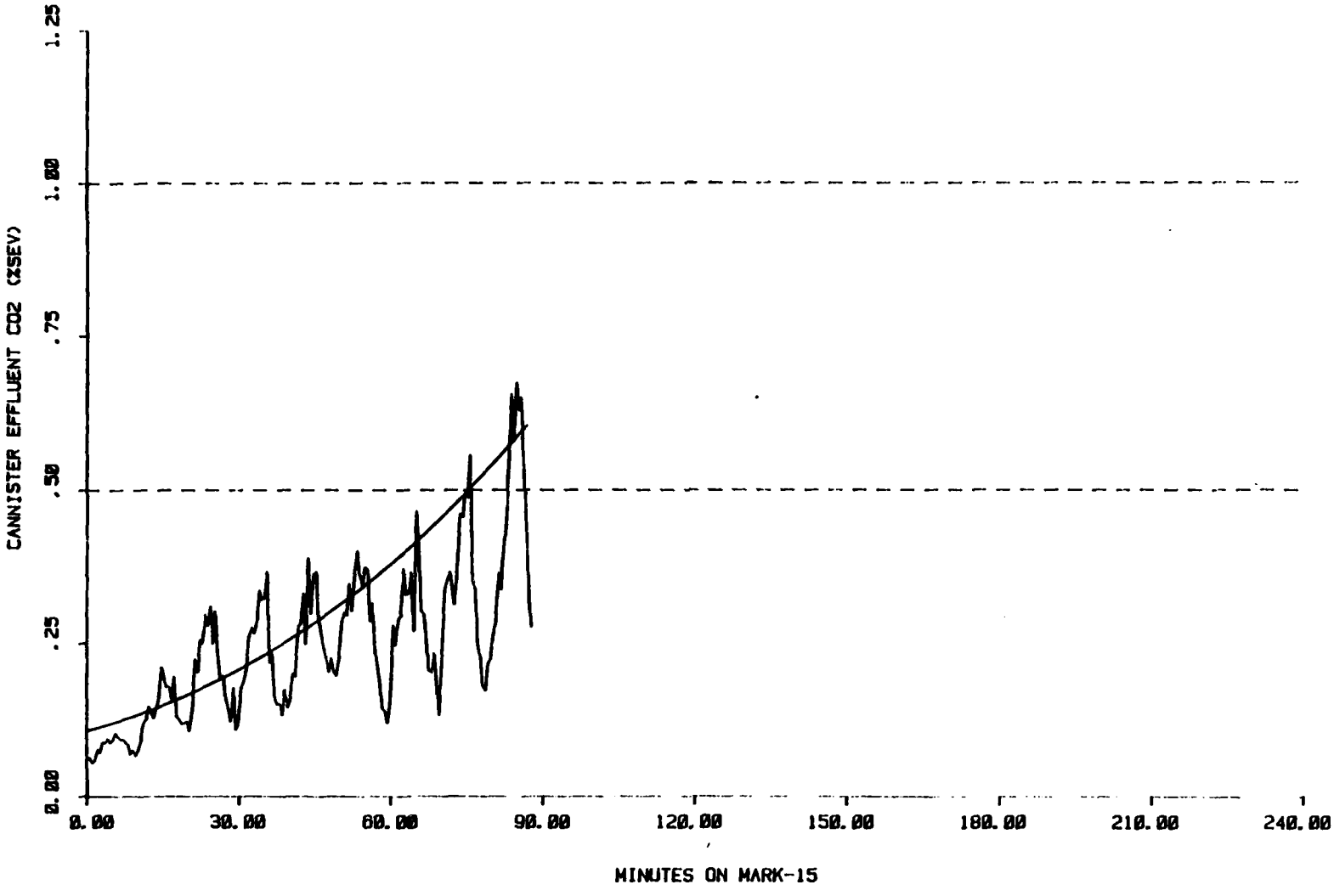

FIGURE 6A. MARK-15 CANNISTER DURATION 13.4°C/65FSW DIVER #6 20 JANUARY 1983 MEAN VO_2 = 1.58 L/MIN (STPD)

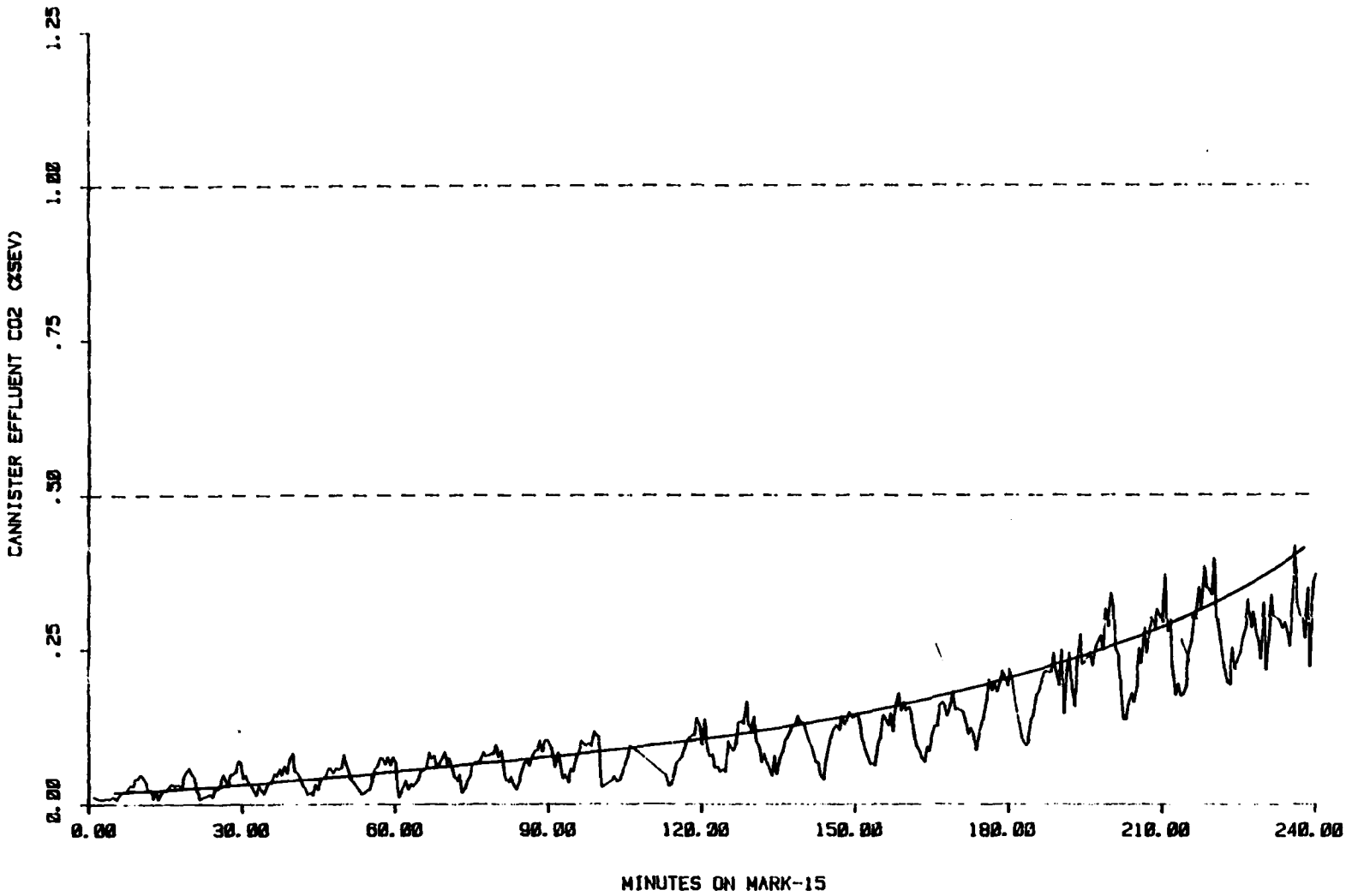

FIGURE 7A. MARK-15 CANNISTER DURATION 13.4°C/65FSW DIVER #6 20 JANUARY 1983 MEAN VO_2 = 1.50 L/MIN (STPD)

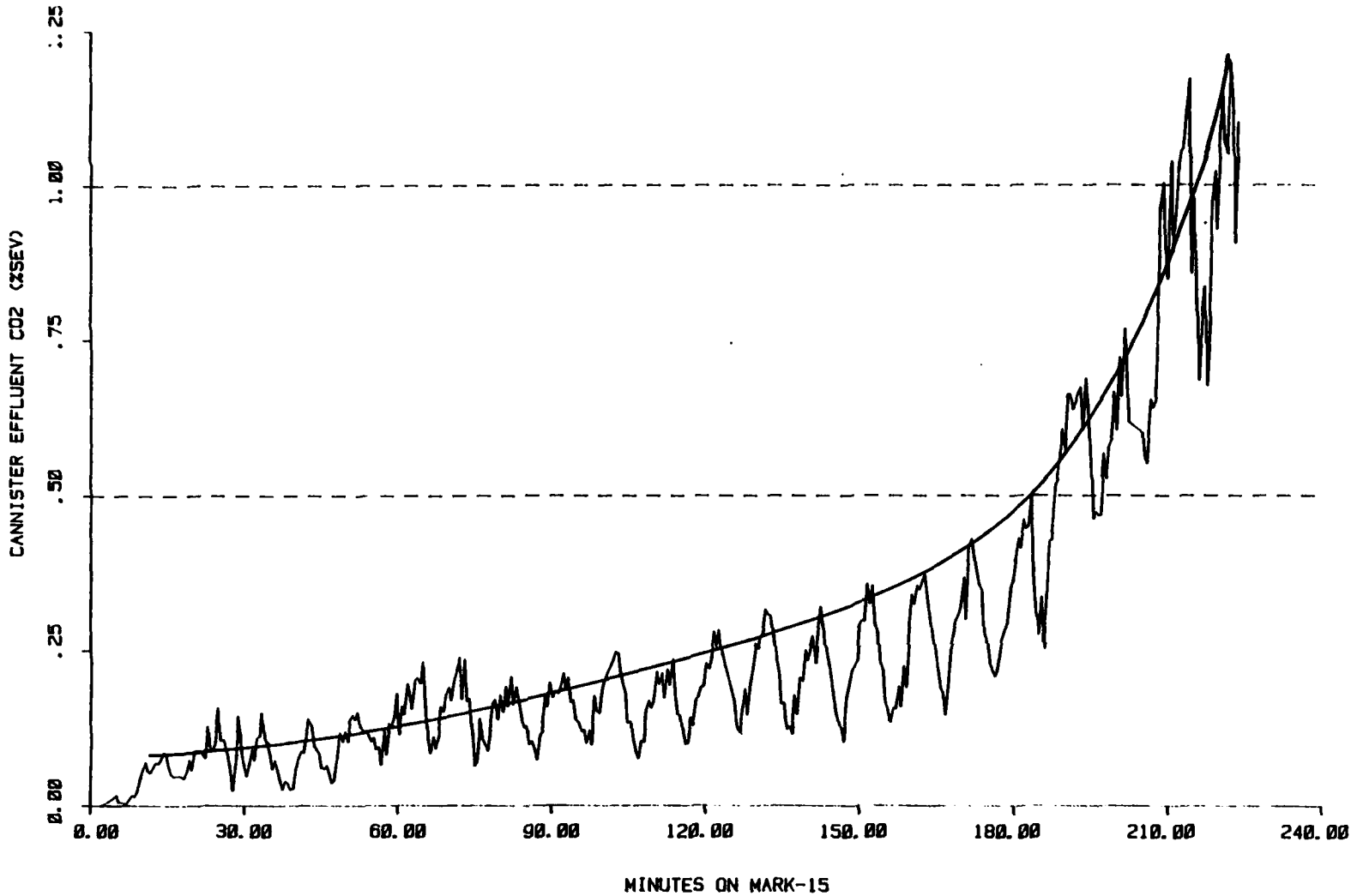

FIGURE 8A. MARK-15 CANNISTER DURATION 2°C/65FSW DIVER #2 18 JANUARY 1983 MEAN VO_2 = 1.56 L/MIN (STPD)

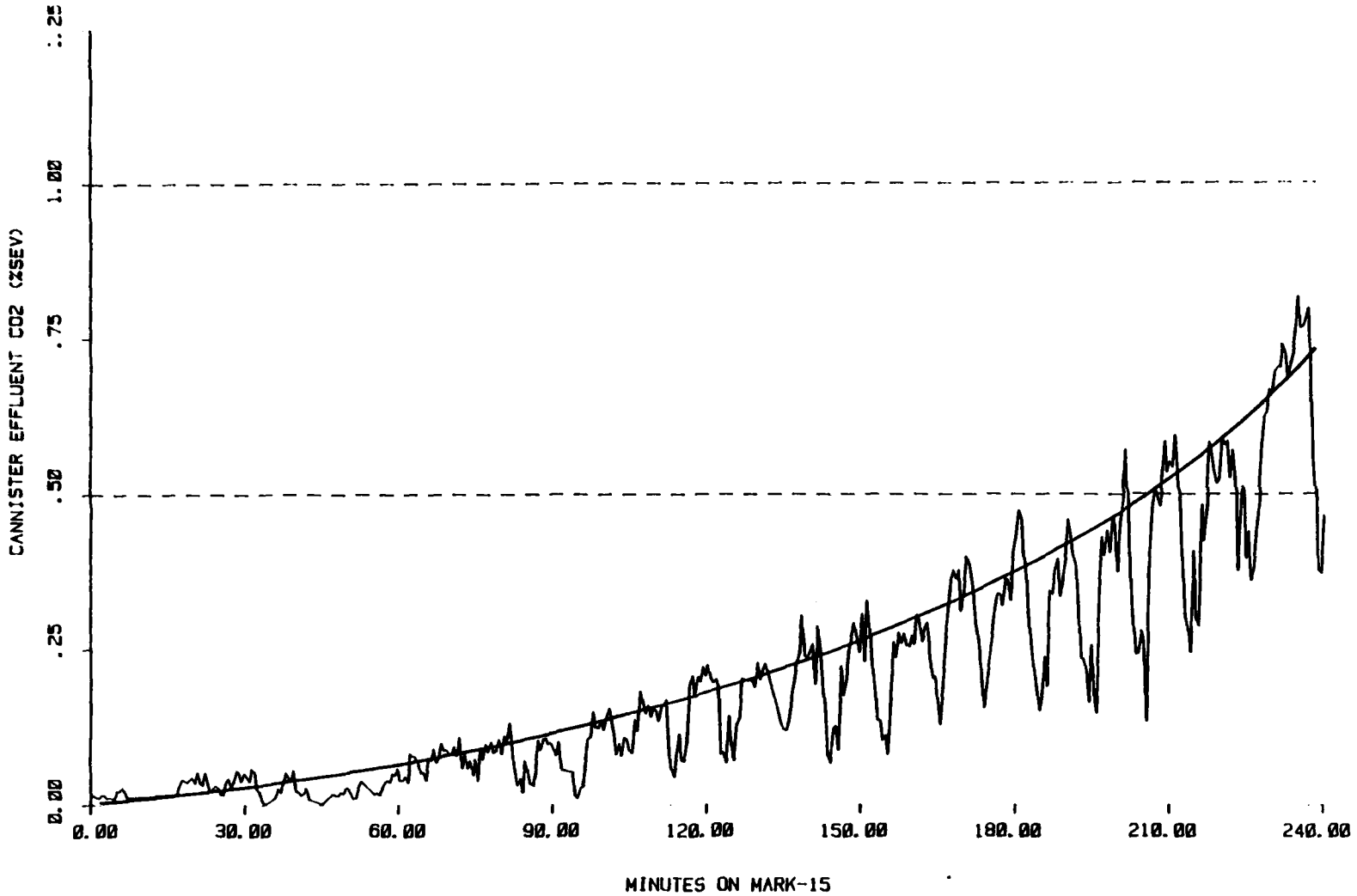

FIGURE 9A. MARK-15 CANNISTER DURATION 2°C/65FSW DIVER #3 17 JANUARY 1983 MEAN VO_2 = 1.66 L/MIN (STPD)

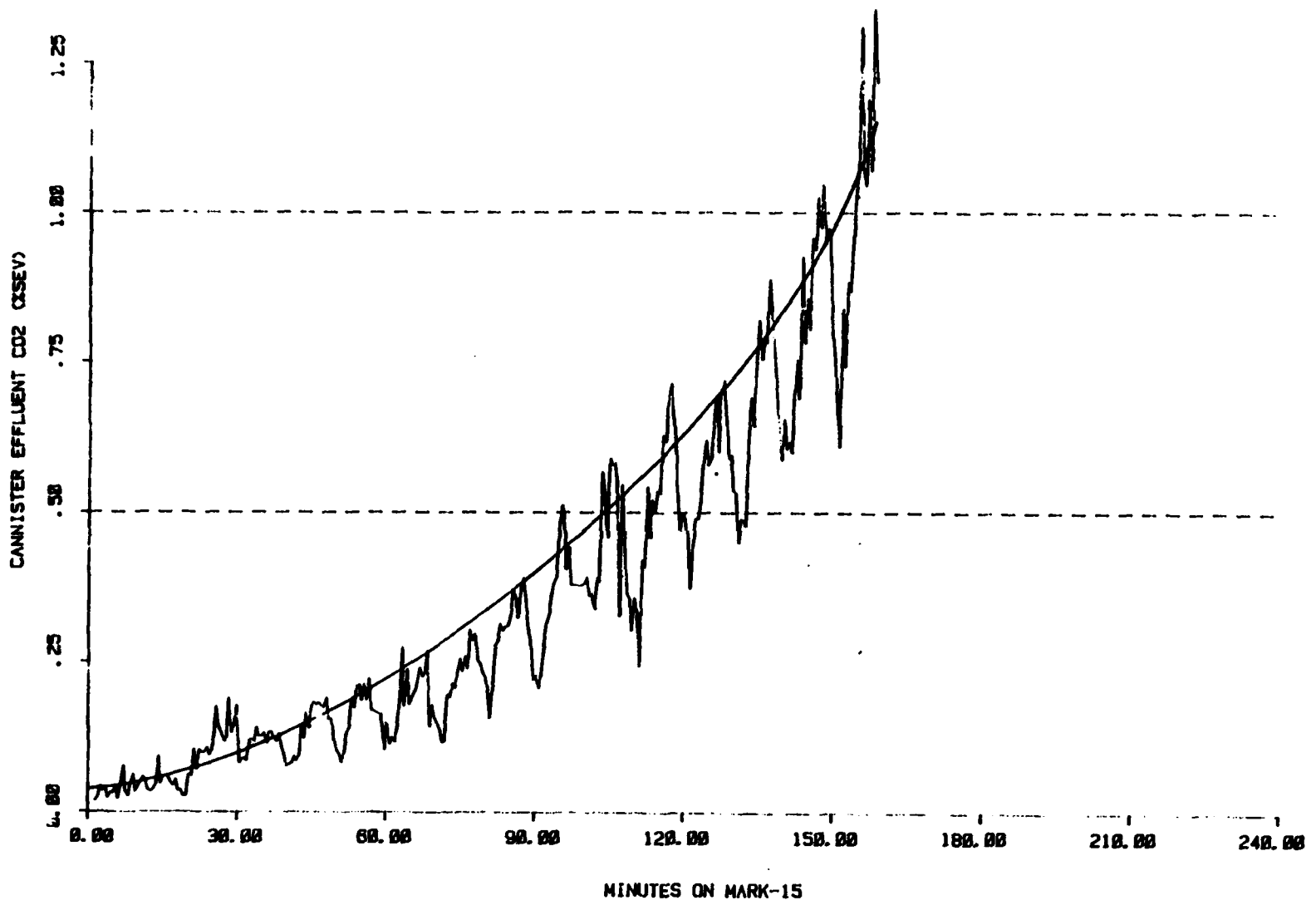

FIGURE 10A. MARK-15 CANNISTER DURATION 2°C/65FSW DIVER #4 18 JANUARY 1983 MEAN VO_2 = 2.11 L/MIN.(STPD)

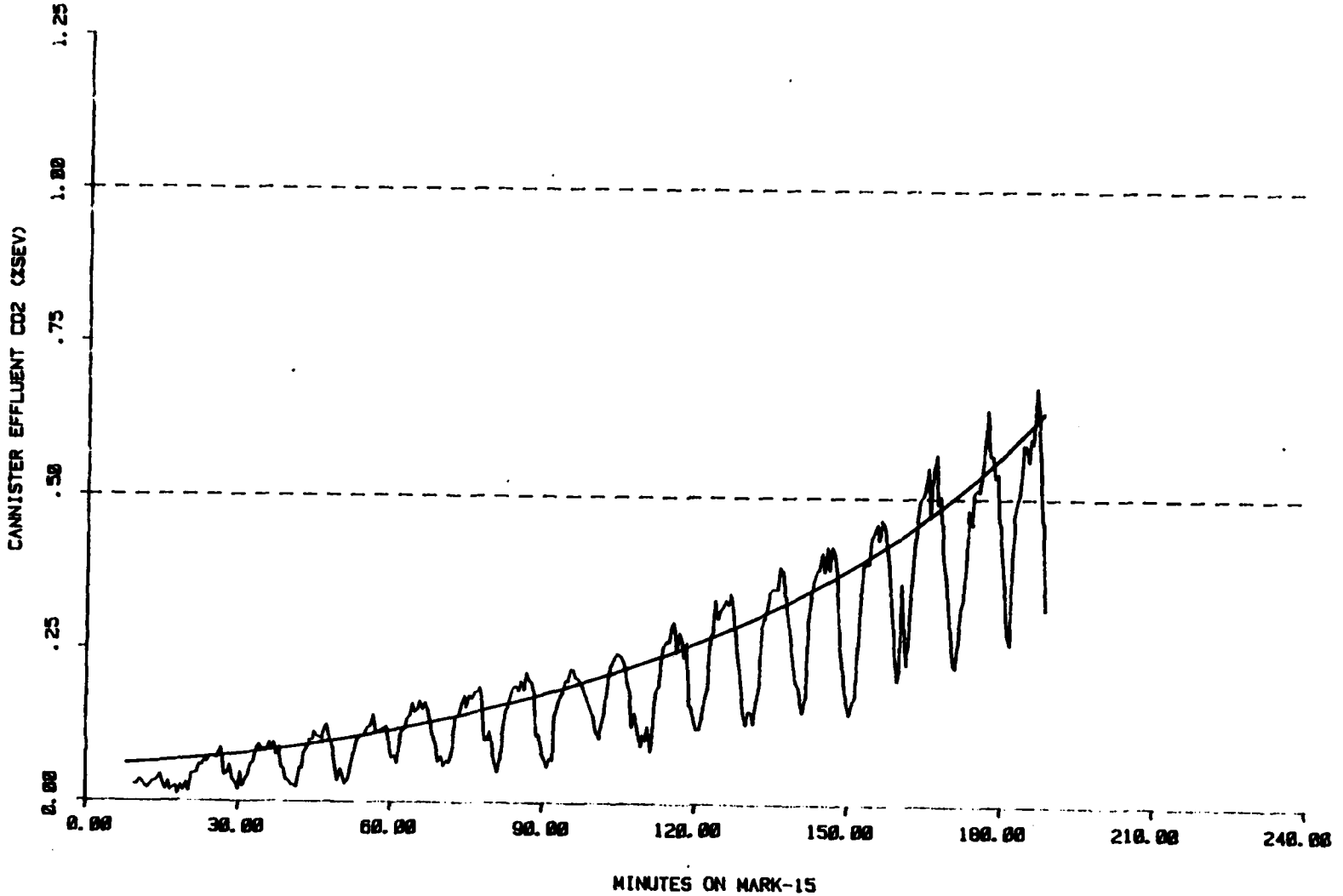

FIGURE 11A. MARK-15 CANNISTER DURATION 2°C/65FSW DIVER #5 18 JANUARY 1983 MEAN VO_2 = 1.46 L/MIN (STPD)

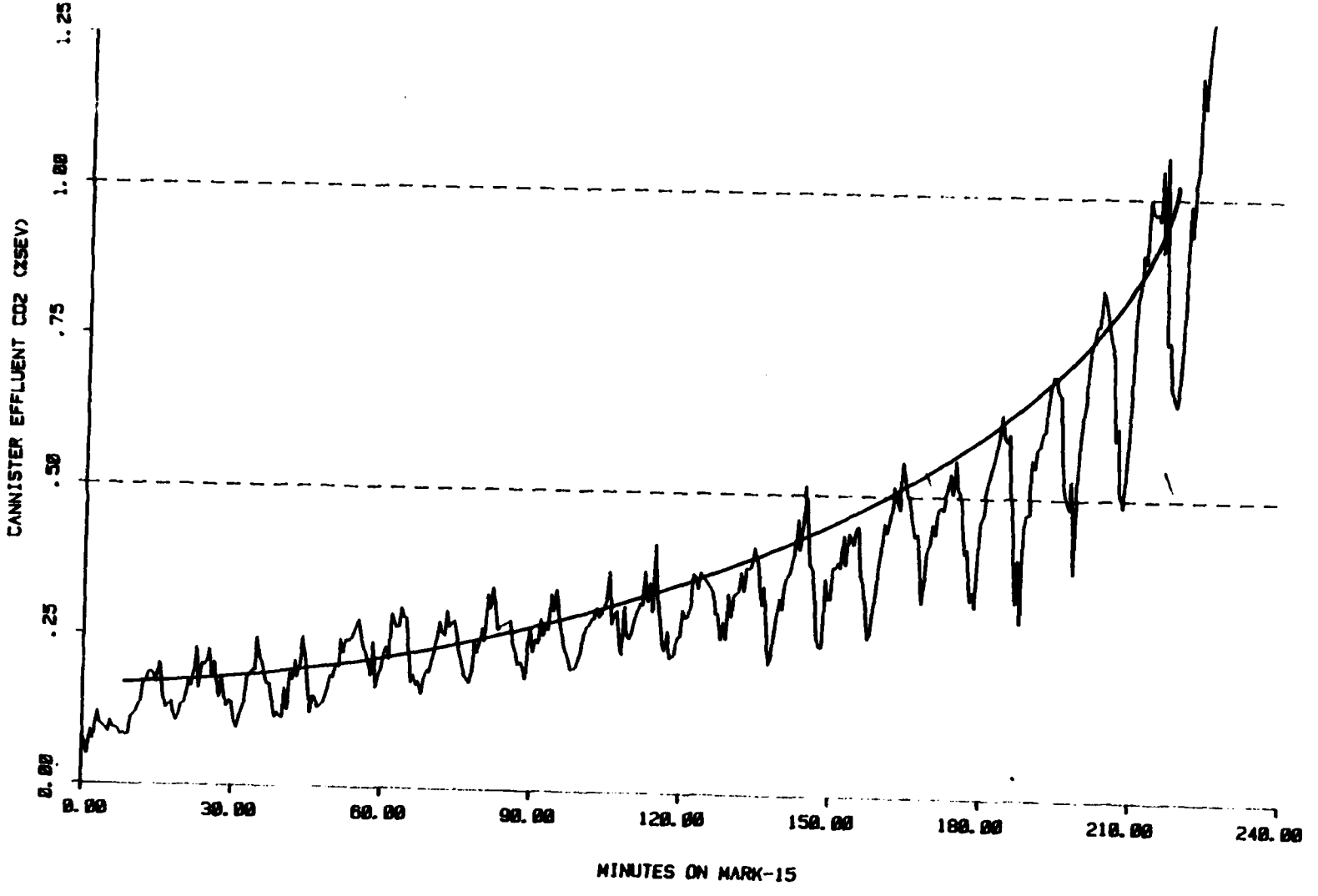

FIGURE 12A. MARK-15 CANNISTER DURATION 2°C/65FSW DIVER #6 18 JANUARY 1983 MEAN VO_2 = 1.85 L/MIN (STPD)